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Video Method of Measuring Field-of-View of Electro-optical Devises Versus Eye Clearances

By

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Aircrew Health and Performance Division

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A miniature charged couple device (CCD) video camera was used to determine the fields-of-view (FOV) with changes in viewing distances (vertex distance) for the standard 18-mm eyepiece ANVIS, a 25-mm eyepiece ANVIS, and two different diameter nonoptical apertures. The data were graphed and compared with theoretical and subjective values (Kotulak, 1992) for FOVs vs eye clearance for the standard 18-mm eyepiece ANVIS. The results indicate that the video camera used in this study approximates both the theoretical and subjectively measured FOV vs eye clearance functions with slight deviation. Computer generated ray traces and subjective assessment with the 25-mm eyepiece confirmed that the marginal rays for the maximum viewable FOVs were blocked at the designed eye position by the aperture on the back plate in front of the fiber optic twist of the intensifier tube.

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Introduction

Various optical and electro-optical (EO) devices are used by the military for target and obstacle detecting, identifying, seeing at night and through smoke, etc. Examples of these devices are binoculars, weapon sights, night vision goggles such as the aviator night vision imaging system (ANVIS), and helmet-mounted displays for pilotage as used in the Apache helicopter and to be used on future weapon systems. All of these imaging devices are required to be compatible with corrective lenses and/or protective masks.

Compatibility with optical and EO devices implies that sufficient field-of-view (FOV) with the device can be obtained without degrading performance when wearing standard military spectacle corrections, current protective mask, and headgear. Exactly what minimum size FOV is sufficient for a specific task has not been determined. However, we generally assume that any reduction in the FOV will at least affect detection times and probability, even though the reductions may not be operationally significant.

When using spectacles and/or protective masks with optical and EO devices, the minimum eye clearance distances typically increase. As the eye clearance increases beyond the full FOV point for the particular device, the FOV through the imaging device will be reduced.

If an optical or EO device acted like a simple "knot hole" for the exit aperture, the changes in FOV with increasing eye clearance could be estimated by using the tangent function for one-half the exit pupil (knot hole) diameter and assuming the location and size of the pupil of the eye. However, the calculations and modelling become more complex with multiple optical elements and apertures in the eyepieces, and with changing observer's pupil sizes and eye movements.

As the apparent FOV is reduced with increasing eye clearances, peripheral objects in the FOV first appear to dim from vignetting before they are fully occluded. This vignetting, or dimming, is primarily a function of the size of the entrance pupil of the observer or the imaging device. In this study, the end point for the camera clearance distance was the maximum distance from the device that a given FOV marker was visible on the monitor. This meant that some vignetting would occur before occlusion.

ANVIS FOV requirements are 40 degrees, +1 or -2 degrees according to MIL-A-49425(CR), Aviator's Night Vision Imaging System, AN/AVS-6(V)1, AN/AVS-6(V)2; therefore, the manufacturer is in compliance with an ANVIS FOV of between 38 and 41 degrees.

FOV versus vertex distance for the 18-mm eyepiece ANVIS was measured in a previous laboratory study using 20 subjects (Kotulak, 1992). The FOV was measured at 8 positions as the vertex distance varied from 17 to 52 mm in 5 mm increments. The subjects fixated at the edge of the FOV in the direction of the target. Using regression analysis with all the data collected of the vertex distances and the measured FOVs, the following equation was derived:

$$y = -0.54x + 49.3$$

where y = FOV in degrees
x = vertex distance in millimeters

If the data points above 37 mm are excluded (the maximum vertex distance measured for the full-aft position in the field study using 105 subjects was 36 mm), and the 17 mm vertex distance is excluded (within the maximum possible FOV), then the equation from the regression to determine the FOV (y) of the four included data points from 22 to 37 mm vertex distance (x) becomes $y = -0.66x + 53.3$. Subtracting 1.8 mm from the vertex distances to obtain eye clearance values, the equation becomes the following:

$$y = -0.66x + 52.1$$

The objectives of this study were: (1) to correlate previously obtained FOV versus vertex distance data for the standard 18-mm ANVIS eyepiece with data obtained with the miniature charged couple device (CCD) camera and theoretical calculations; and (2) to determine the relationship between the FOV and eye clearance for the 25-mm ANVIS eyepiece using only the miniature CCD camera.

Methods

Description of the equipment

1. Watec black and white CCD camera, model WAT-310*. This camera is approximately 6 cubic inches in total volume, with approximately 6-mm objective lens diameter. The FOV is approximately 48 degrees. Output signal is RS-170 to a high resolution 14-inch monitor. The picture on the monitor is selected to be within the outer edges of the monitor so that the edges of the full or restricted FOVs from the CCD camera can be verified.

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* See Appendix A for list of manufacturers

2. Aviator night imaging systems (ANVIS) with 18-mm convex and concave eyepieces and a 25-mm convex eyepiece ANVIS, modified to single tubes or channels.

a. 18-mm convex. The viewable optical diameter of the eyepiece lens closest to the eye (exit pupil) of present 18-mm ANVIS convex (most common) eyepiece is 19.4 mm (measured). The distance from the most rearward part of the eyepiece mount and the edge of the optics, parallel to the optical axis is approximately 1.7 mm.

b. 18-mm concave. The optical diameter of the 18-mm concave eyepiece ANVIS is 19.76 mm (measured). The distances from the most rearward part of the eyepiece mount and the edge and center of the eyepiece optics, parallel to the optical axis, is approximately 0.8 mm and 1.8 mm, respectively.

c. The optical viewable diameter of the production 25-mm eyepiece is 27.2 mm (measured). The distance from the most rearward part of the eyepiece mount and the edge of the convex lens optics is approximately 2.6 mm.

3. Mitutoyo Electronic caliber, model CD-6B*. Caliber has digital output with a range of 150 mm in 1/100 mm units.

4. Optical rail, x-y adjustable table mounts, and adjustable iris aperture.

5. Gentex NVG compatible filters* over the ANVIS objective lenses to allow operation of the ANVIS in a lighted laboratory environment without activating the automatic gain control or damaging the tubes.

6. Diopterscope to adjust eyepiece focus.

7. Air Force 3-bar resolution chart to aid in the adjustment of the ANVIS objective and eyepiece lens focus.

Figure 1 shows the basic apparatus set-up.

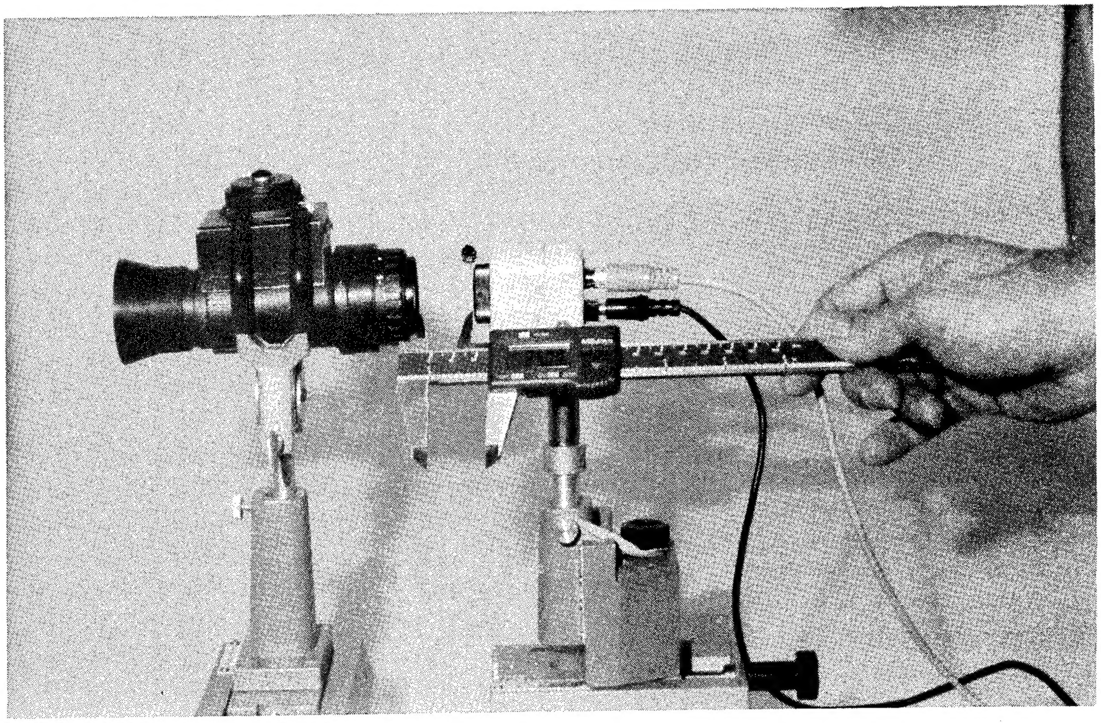

Figure 1. Apparatus set-up.

Procedures

Strips of tan colored masking tape, measuring 3 inches long vertically, were used to mark the FOVs for 40, 39, 38, 36, 35, and 32 degrees on a wall for a 4 meter viewing distance at the center of the FOV. Strips of one inch width were used for 40, 38, 35 and 32 degree positions; 1/2-inch wide strips were used for the 39 and 36 degree positions. The different tape widths were an aid in differentiating the FOV value on the video monitor. The background was black which produced high contrast for both the visual and near infrared spectrum of the image intensifiers.

The ANVIS(s) were mounted on the optical rail using a claw attachment mount. Using the diopterscope, the ANVIS objective lenses were focused for best resolution, and the eyepieces for plano, -0.50, or -1.00 diopters.

The miniature CCD camera was attached to a mount that had very fine linear adjustments (1 mm per turn) in both vertical height and fore-aft movements. The single tube ANVIS (18-mm or 25-mm) was also attached to a mount that was adjustable in lateral translation. An adjustable mechanical iris could be fixed at any aperture from 1 to 35 mm and positioned in place of the ANVIS single tube for the nonoptical FOV versus eye clearance determinations.

Each single tube ANVIS with day filter was positioned with the center of the object lens assembly at four meters from the wall with the FOV markings. The ANVIS was yawed and pitched as needed to center the marked maximum FOV as seen by an observer. The small CCD camera was positioned immediately behind the eyepiece of the ANVIS. Using the fine fore-aft adjustment along the ANVIS eyepiece optical axis, the vertex distances were gradually increased until a given right and left FOV marker was just visible at the edge of the video monitor. To compensate for any small lateral misalignment between the ANVIS and the CCD camera, the lateral adjustment on the mount holding the ANVIS was repositioned for each measurement to assure equal FOVs right and left of the center of the horizontal FOV as viewed on the monitor. The measurements were repeated by decreasing the distance from the camera to the device, and the two measurements for a given FOV were averaged.

Using the digital caliper, the distance between the back of the ANVIS eyepiece mount and the front of the CCD camera lens mount was measured at each FOV for both the 18-mm and 25-mm eyepiece ANVIS.

For the nonoptical aperture FOV versus eye clearance determination ("knot hole effect"), the variable mechanical iris was adjusted to the same diameter as either the 18-mm convex or the 25-mm convex ANVIS eyepiece lenses (19.4 and 27.2 mm, respectively). The minimum clearance distances between the iris and CCD camera were measured with the digital caliper for each FOV.

The theoretical eye clearances (EC) versus FOV for the 19.4 mm exit pupil of the 18-mm ANVIS eyepiece and the 27.2 mm exit pupil for the 25-mm ANVIS eyepiece were also calculated using the tangent function. The location of the pupil within the eye was assumed to be 3 mm with 50% vignetting. The equation was calculated as:

$$EC = \frac{1/2\ d}{\tan(1/2\ a)} - 3$$

where EC = eye clearance in millimeters
d = exit pupil in millimeters
a = FOV angle in degrees

Using the derived regression equations for each FOV versus eye clearance condition measured or calculated, the eye clearance distances that would be required to obtain a 40-degree FOV were then computed.

Results

18-mm ANVIS eyepiece

Figure 2 shows four plots of FOV versus eye clearance for the measured and calculated theoretical values. The solid line depicts the actual measurements using the 18-mm convex ANVIS single tube focused at -1.00 diopters. The dot-dash line is the regression equation derived with 20 subjects from a previous USAARL laboratory study (Kotulak, 1992). Only the data from the 22 to 37 mm vertex distance were included in the regression, and the values were adjusted by -1.8 mm for the difference between vertex and eye clearance measurements. The dashed line is produced with a 19.4 mm diameter aperture (ANVIS exit pupil diameter) when measured with the CCD camera, and the dotted line is the theoretical plot based on the calculated tangent function.

Figure 3 shows a comparison between the 18-mm concave and convex ANVIS eyepieces when focused at -0.50 diopters. Kotulak's regression equation essentially matches the 18-mm concave lens eyepiece data except the slope is slightly flatter. As noted in the equipment description, the 18-mm concave eyepiece had a slightly larger optical exit pupil diameter (19.76 mm) than convex lens eyepiece (19.4 mm), and the outer lens edges of the concave design were closer to the eyepiece mount.

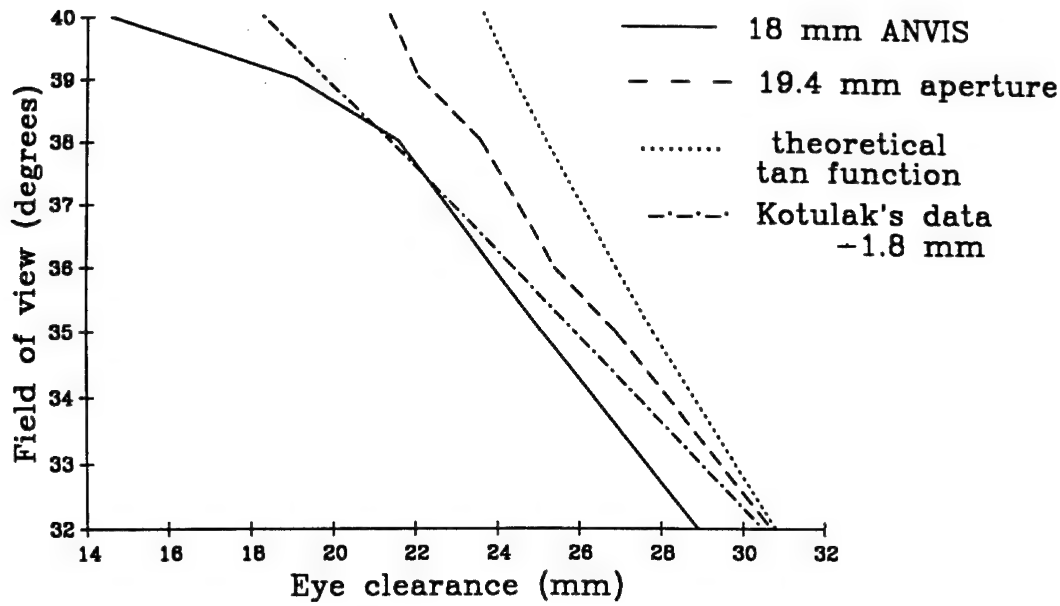

Figure 2. Plots of FOV versus Eye Clearance for 18-mm convex ANVIS eyepiece 19.4-mm mechanical iris theoretical calculated data Kotulak's data minus 1.8 mm.

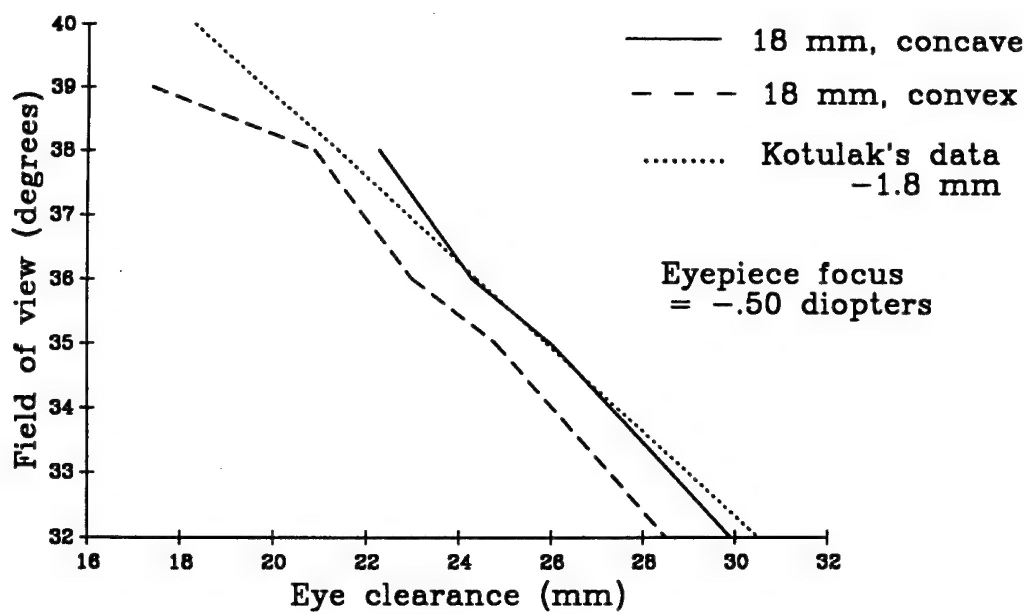

Figure 3. Comparison of convex and concave 18-mm ANVIS eyepieces with Kotulak's data.

Table 1 lists the slopes (b) and intercept values (a) of regression equations to determine FOV (y) for a given eye clearance value (x). The plots include the four data points between 32 and 38 degrees. The regression equation form is the following:

$$y = bx + a$$

where y = FOV in degrees
b = slope coefficient
x = eye clearance in millimeters
a = y- intercept value in degrees

The calculated eye clearance distances (mm) to obtain 40-degree FOV based on the regression equations are labelled EC40.

Table 1

Regression analysis of the 18-mm ANVIS eyepiece

Function	slope(b)	intercept(a)	EC40
18-mm ANVIS,-1.00 D, convex	-0.82	55.6	19.0
19.4 mm aperture, CCD	-0.83	57.2	20.7
subjective data, 20 subj.	-0.66	52.1	18.3
theoretical, tan function	-1.06	64.7	23.3
18-mm ANVIS,-0.50 D, convex	-0.77	54.1	18.3
18-mm ANVIS,-0.50 D, concave	-0.77	55.0	19.5
18-mm ANVIS, 0.00 D, convex	-0.82	54.7	17.9

Note that the slope of the mechanical aperture data (19.4 mm aperture) almost perfectly matches the slope of the actual tube when measured with the CCD camera between 32 and 38 degrees FOV (Figure 2). The theoretical function line is slightly steeper than the ANVIS or nonoptical aperture measured functions. The slope of the subjective data function of eye clearance and FOV is slightly flatter than the CCD camera measured values. However, the differences in the subjective regression and optical and nonoptical measured values with the CCD camera are small, and the plot falls between the two functions from 32 to 38 degrees FOV.

The calculated eye clearance value to obtain 40 degrees FOV (EC40) for the theoretical tangent function in Table 1 is conspicuously higher than the other values. However, the calculation does not include any distance from an eyepiece lens opening at the edge and an eyepiece mount (1.8 mm). When this difference is included, the theoretical calculation for EC40 is 21.5 mm.

From 38 to 40 degrees FOV with the ANVIS, the slope of the curve flattens out for the measured values, while the mechanical apertures do not show this effect. This flattening of the FOV plot versus eye clearance above 38 degrees was also found in the previous USAARL study using subjects (Kotulak, 1992).

25-mm ANVIS eyepiece

Figure 4 shows three plots of FOV versus eye clearance for the measured and calculated theoretical values. The solid line shows the actual measurements using the 25-mm ANVIS single tube focused at -1.00 diopters. The dashed line is the measured function using a 27.2 mm diameter aperture, and the dotted line is the theoretical plot based on the calculated tangent function and assuming the entrance pupil is 3 mm behind the cornea.

Figure 5 shows the effect of eye clearance for a given FOV with changes in eyepiece diopter power. Increasing minus lens power tends to increase eye clearance values as the FOV decreases. The mechanical movement distance of the eyepiece away from the eye with minus induced lens power is approximately 0.7 mm per diopter change in focus.

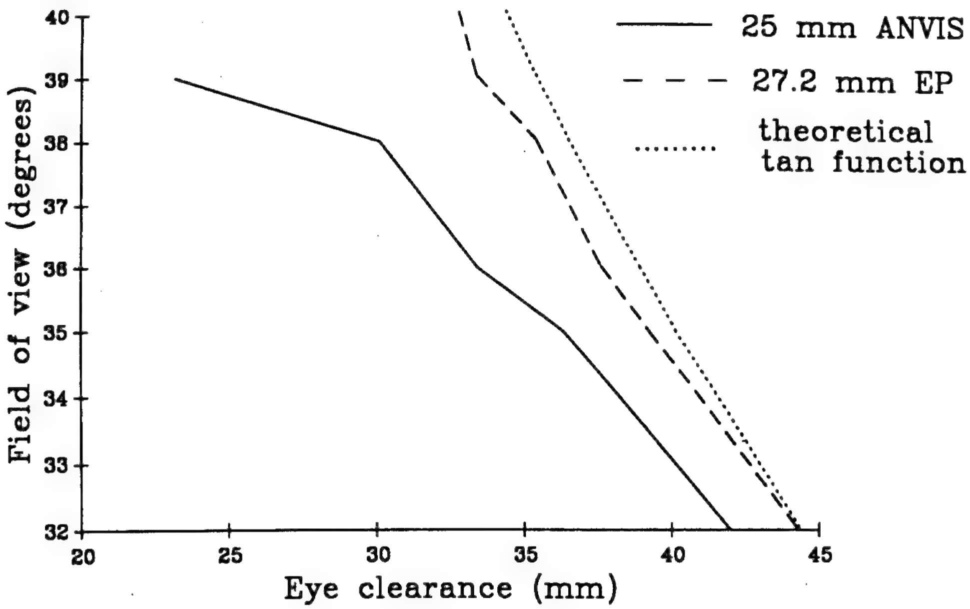

Figure 4. Plots of FOV versus Eye Clearance for 25-mm ANVIS eyepiece 27.2-mm mechanical iris theoretical calculated data.

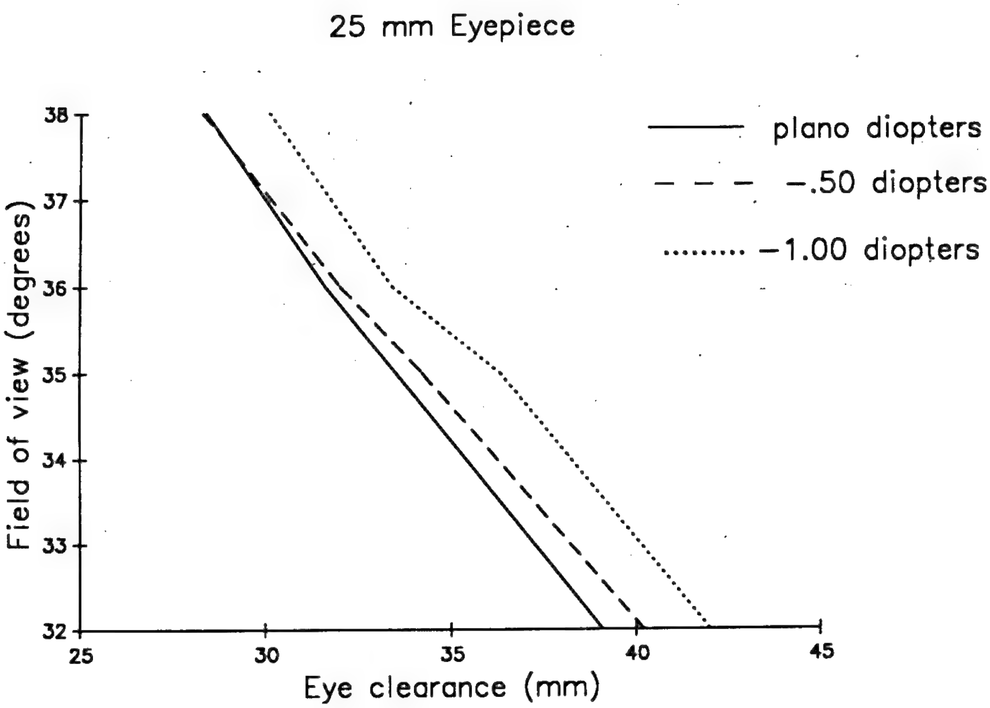

Figure 5. Effects of diopter focus adjustment on eye clearance.

Table 2 lists the slope (b) and intercept values (a) of the linear regressions between FOV (y) and eye clearances (x) from 32 to 38 degrees for the data collected and calculated. The regression equation is y = (b)x + (a). The calculated eye clearance distance (mm) required to obtain a 40-degree FOV from the regression equations is labelled EC40.

Table 2

Regression analysis of the 25-mm ANVIS eyepiece

Function	slope(b)	intercept(a)	EC40
25-mm ANVIS, -1.00 D	-0.49	52.8	26.1
27.2 mm aperture, CCD	-0.66	60.9	31.7
theoretical, tan function	-0.75	65.4	33.9
25-mm ANVIS, -0.50 D	-0.50	52.1	24.2
25-mm ANVIS, plano D	-0.56	53.7	24.5

As previously mentioned for the 18-mm eyepiece, the theoretical tangent function calculations to determine the eye clearances for 40-degree FOV (EC40) do not include the 2.6 mm distance from the edge of the eyepiece lens and the eyepiece mount. When this distance is included, then the EC40 for the theoretical calculation is 31.3 mm.

Discussion

The comparisons of the FOV versus EC between the theoretical and the mechanical apertures suggest that the optics in the little CCD camera affect the slope of the function slightly. That is, with increasing fields of view, the camera measurements require less eye clearances than predicted on actual or calculated exit pupil diameters alone. Comparison of the subjective data and measured data with the CCD camera on the 18-mm ANVIS also suggests that the eye shows a slight deviation from the theoretical calculations, which is probably due to the optics and pupil size of the eye and CCD camera.

The departure from a linear function for eye clearance with either the 18-mm or 25-mm eyepiece ANVIS above 38 degrees FOV suggests that the simple "knot hole" effect as shown with the apertures to limit FOV is reliable only below 38 degree FOV. In other words, something besides the outer diameter of the lens closest to the eye in the ANVIS eyepiece is vignetting or obscuring the FOV above 38 degrees.

It was noted during the measurements, particularly with the 25-mm eyepiece, that the FOV was about 38 degrees when the circular aperture on the face of the fiber optic twist on the image intensifier tube came into view. It had been assumed that when the iris-like aperture on the image intensifier tube was visible through the eyepiece, then the maximum FOV had been obtained.

Follow up

On examination of the three ANVIS image intensifier tubes used in this study, we measured the diameter of the aperture, or iris, on the back plate around the fiber optic twist to be within $\pm$ 0.1 mm of 18.9 mm. The distances from the edge of the fiber optic twist to the edge of the iris on the back plate was between 2 and 2.6 mm. See Figure 6 for a photograph of the ANVIS tube showing the restrictive aperture in front of the fiber optic twist.

Telephonic discussions with Mr. Ed Bender at NV&EOL provided information on intensifier tube component specifications, which were developed for the standard 18-mm eyepieces. The aperture on the back plate is specified at 18.9 mm with a depth of 4 mm, $\pm$ 1.0 mm between the back plate and fiber optic twist along the optical axis.

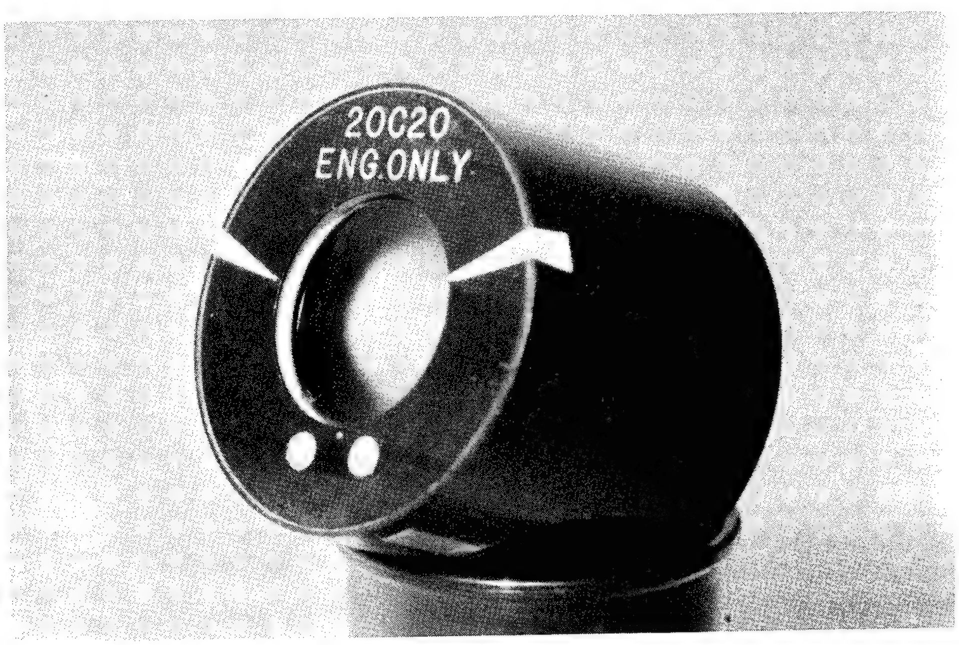

Figure 6. ANVIS tube, three-quarter view, showing iris in front of fiber optic twist.

Optical ray trace data

Using a simple optical ray trace computer program (Beam 3 Optical Ray Tracer by Stellar Software, version 3.28, 1987), an analysis of the 25-mm eyepiece for FOV versus eye clearance was initiated. The prescription data for the production 25-mm eyepiece was furnished by the Night Vision Laboratory, Fort Belvoir, VA (Hall, 1995).

The eye pupil used for the ray trace was initially 5 mm in diameter and located 25 mm from the first lens in the eyepiece. The diameter of the image on the fiber optic twist was assumed to be 18 mm. As specified for ANVIS tubes, an iris was positioned 4 mm in front of the center of the fiber optic twist with an aperture of 18.9 mm for the computer program (Bender, 1995).

Ray traces confirmed that the 40-degree FOV could not be seen at the 25-mm vertex distance with a 5-mm pupil due to the blockage of the marginal rays from the 18.9-mm diameter aperture on the back plate in front of the fiber optic twist on the tube. This aperture limited the vertex distance for a 5-mm exit pupil to approximately 20 mm. Ray traces also showed that at the 25-mm vertex distance, with a 27-mm entrance pupil for the eyepiece, an exit pupil diameter of 7.0 mm could be obtained without vignetting for the 40-degree FOV, if the aperture on the back plate of the image intensifier tube were increased to 19.8 mm. Calculations further show that with a 5-mm exit pupil, the 25-mm eyepiece would have a vertex distance of approximately 28 mm with a 40-degree FOV, if there were no restrictions from the diameter of the back plate on the tube.

In Figure 7 the marginal rays that are blocked by the iris around the fiber optic twist are indicated. With the 18.9-mm diameter back plate aperture, the FOV is restricted to 38 degrees at 25 mm vertex distance for a 5-mm exit pupil. The outlines of the individual lenses in the eyepiece were removed due to proprietary considerations.

We did not consider with the ray trace program that the back plates around the fiber optic twist may not be perfectly centered. When removing one of the tubes from the housing after the eye clearance measurements, the back plate fell off. We may not have positioned the back plate within the tolerances of the human eye to visually detect a displacement of the aperture from center alignment.

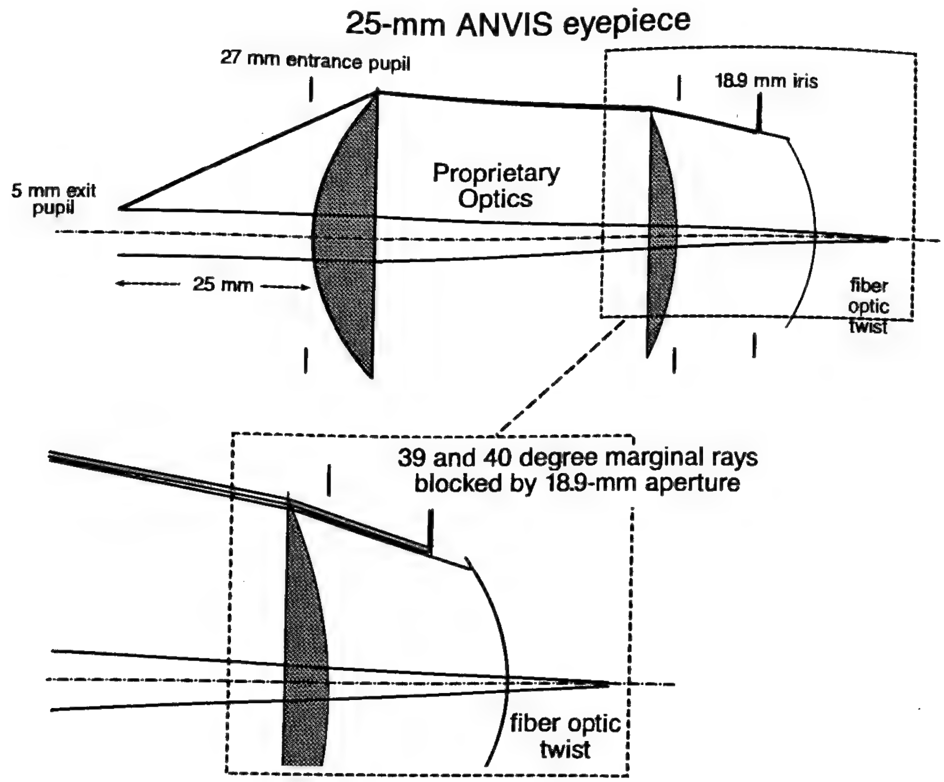

Figure 7. Ray trace of 25-mm eyepiece showing blockage of marginal rays for 40-degree FOV

Subjective laboratory assessment

Because the intensifier tubes used in the eye clearance versus FOV measurements were for engineering use only, prototype, or preproduction samples, the investigator obtained three pairs of standard fielded ANVIS, manufactured between 1986 and 1990, to subjectively assess the effects of the aperture on the back plate of the image intensifier tubes. The standard 18-mm eyepieces were replaced with the 25-mm eyepiece lenses on these ANVIS, and the investigator visually determined whether the marginal rays for the maximum FOV were blocked by the aperture on the back plate of the tubes. The observer used ambient illumination slightly above the level required to activate the automatic brightness control of the image intensifier and viewed a white background that was greater than the ANVIS FOV.

The investigator easily saw the blockage of the marginal rays by the back plate aperture on all six tubes by viewing slight imperfections at the edges of the FOV and changing the fore-aft and/or interpupillary distance, tilt, or vertical adjustments. The actual amount of FOV blocked in degrees was not measured, but on one tube, the minor width of two faintly visible "chicken wire" patterns were blocked by the back plate before vignetting occurred from the entrance pupil of the 25-mm

eyepiece. It also appeared that several of the apertures on the back plates were not exactly centered. This was more noticeable on upward gaze.

Conclusions

For quick and accurate assessment of changes in FOV with eye clearance for EO devices, the small CCD camera with a 6-mm entrance pupil used in this study is a good human eye substitute. Multiple lens EO devices may deviate from the simple "knot hole" calculations of FOV versus eye clearance. Some of these deviations may not have been known to the optical designers due to incomplete information on the tube design. Likewise, as in this case, the tube manufacturers were evidently unaware that the diameter of the iris around the fiber optic twist would restrict the marginal rays with the 25-mm eyepiece.

If the aperture around the fiber optic twist on the ANVIS image intensifier tube were increased beyond 20-mm diameter and/or moved closer to the fiber optic twist, then the maximum eye clearance for the maximum FOVs (40 degrees) could be increased, especially for the 25-mm eyepiece ANVIS.

Recommendation

This report will be forwarded to the Night Vision and Electro-Optics Laboratory for review, with a recommendation that in the future all mechanical dimensions of the image intensifier tubes, including the potential restrictive apertures, be furnished to the optical designers. Also, the optical designers should provide specifications on the minimum size and location for any potential apertures that could affect the FOV to the image intensifier tube manufacturers.

Both the optical and image intensifier tube designers should be consulted to determine if there are any draw backs or trade-offs if the aperture on the back plates are enlarged.

The actual size increase in the aperture on the back plate of the intensifier tube for the 25-mm eyepiece should be determined using both manufacturing tolerances and focus adjustments with a ray trace program such as CODE V.

Since many of the aviation units have expressed interest in replacing their ANVIS 18-mm eyepieces with the 25-mm ones, the image intensifier tube manufactures, depot maintenance, etc. should be consulted to determine the most cost effective and safe method to modify the fielded image intensifier tubes by enlarging the apertures on the back plates.

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Appendix B

Manufacturers' list

Watec Co., LTD, Japan
Distributed by Industrial Vision Source
1220 Champion Circle #100
Carrollton, TX 75006
1-800-627-6734

Mitutoyo/MTI Corp
965-A Corporate Rd.
Aurora, IL 60504

Gentex Corp
Filtron Div.
P.O Box 315
Carbondale, PA 18407

Special distribution

U.S. Army Aviation Technical Test Center
ATTN: STEAP-FS (Richardson & Block)/ STEAP-MP-P
Ft. Rucker, AL 36362-5276

U.S. Army Aviation Center
ATTN: ATZQ-CDM-S (MAJ K. Graef)
Ft. Rucker, AL 36362-5000

USAAVNC
DCD, ATTN: ATZQ-CDM-A (Dan Mason)
Ft. Rucker, AL 36362

USAAVNC
Night Vision Device Branch
Aviation Training Brigade
Ft. Rucker, AL 36362

Commander
U.S. Army Safety Center
ATTN: CSSC
Ft. Rucker, AL 36362

Litton Systems, Inc.
Electron Devices Division
1215 South 52nd Street
Tempe, AZ 85281

Intevac
Electro-Optical Sensors Division
601 California Avenue
Palo Alto, CA 94304-0883

Naval Aerospace Medical Laboratory
ATTN: Lieutenant Commanders Mittelman and Stills
Pensacola, FL 32408

U.S. Army Research Laboratory
Human Research and Engineering Directorate
NBC Team, ATTN: AMSRL-HR-MM (Harrah & McMahon)
Aberdeen Proving Ground, MD 21005-5071

Project Manager for NBC Defense Systems
ATTN: AMCPM-NNM-A
Aberdeen Proving Ground, MD 21010-5423

U.S. Army Medical Materiel Development Activity
ATTN: SGRD-VMA
Ft. Detrick, Fredrerick, MD 21702-5009

Director
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ATTN: AMSAT-R-Z
4300 Goodfellow Boulevard
St. Louis, MO 63120-1798

Commanding Officer
Armstrong Laboratory
ATTN: Lee Task, Brian Tsou
Wright-Patterson AFB, OH 45433

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IMO Industries, Inc.
Electro-Optical Systems
2203 W. Walnut Street
Garland, TX 75042

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7365 Plantation Road
Roanoke, VA 24019

Commander
Aviation Applied Technology Directorate
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Ft. Eustis, VA 23604-5577